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I, LEANNE MYNOTT, MANAGER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. 2003906776 for a patent by THE COMMONWEALTH OF AUSTRALIA as filed on 05 December 2003.

WITNESS my hand this  
Sixteenth day of December 2004

A handwritten signature in dark ink, appearing to be 'LM' or 'Leanne Mynott'.

LEANNE MYNOTT  
MANAGER EXAMINATION SUPPORT  
AND SALES



AUSTRALIA  
Patents Act 1990

PROVISIONAL SPECIFICATION

Applicant:

THE COMMONWEALTH OF AUSTRALIA

Invention Title:

FOIL SENSOR

The invention is described in the following statement:

## FOIL SENSOR

### FIELD OF THE INVENTION

The present invention relates to a method of manufacturing  
5 foil sensors, and to foils and foils sensors manufactured  
by that method. Such foil sensors are of particular but  
by no means exclusive suitability as corrosion sensors for  
monitoring corrosion in inaccessible locations or under  
10 protective surfaces, and for monitoring the structural  
health of high value structures.

### BACKGROUND OF THE INVENTION

Foil sensors are composed of a thin metal foil bonded to  
an insulating substrate, and are used in monitoring the  
15 structural health of high value structures.

However, existing sensors are manufactured by techniques  
that in each case are suitable for only a small range of  
foil materials. Consequently, such foils are not  
20 generally made of the parent structural material to be  
monitored; the corrosion detected by the sensor must  
therefore be related by some means to the corrosion on the  
parent structure. This may be described as an indirect  
monitoring approach; it can produce errors and it  
25 restricts the use of existing sensors to structures where  
the sensor/structure relationship is known.

Further, existing small structure manufacturing techniques  
used in the manufacture of sensors means that only a  
30 limited number of materials can be used in sensor  
manufacture, so the breadth of existing sensor types is  
small. These existing techniques also have difficulty  
producing thin foils and adhering thin foils to rigid  
insulating backings.

35

### SUMMARY OF THE INVENTION

According to the present invention, there is provided a

method of manufacturing a foil sensor, involving:

bonding a thin metal foil to an insulating substrate and thereby forming a sensor blank;

5 laser machining said foil to produce at least one trench for defining one or more foil tracks, said trench being at least equal in depth to the thickness of the foil; and

filling said trench with a polymer;  
whereby said foil tracks are electrically  
10 isolated from one another.

The method preferably includes forming said metal foil from a parent foil that is substantially identical with the material of the structure to be monitored.

15

The method may also include laser machining said foil to produce one or more back slots, said slots being equal in depth to the full thickness of said sensor.

20 The method preferably includes preparing the metal foil by machining a sample of parent material to a desired final thickness. More preferably the method includes alternately machining both faces of thick parent material until said final thickness is achieved.

25

Machining in this manner removes any surface finish due to processes such as rolling, plating or heat treating, produces a relatively stress free material, and thins the parent material without effecting the material properties  
30 (unlike thinning by chemical milling or rolling).

Preferably the method includes preparing the foil for said bonding by applying a chemically resistant film (such as a polyester tape) to a first face of said foil, and dipping  
35 the other face of said foil in a bond enhancer (such as a 1% silane solution), wherein said first face is ultimately the exposed face of said sensor and said chemically

resistant film protects said first face from said bond enhancer.

5 Preferably the method includes drying said foil and then removing said film.

Preferably said substrate comprises a plurality of layers of fibreglass prepeg.

10 Preferably the method includes preparing said sensor blank by coating said sensor blank on the surface comprising the ultimate sensor side of said sensor with a chemically resistant coating solution, to protect said surface from contamination during sensor processing. More preferably  
15 the method includes then drying said sensor blank.

Preferably said laser machining said foil comprises producing slots, in one embodiment of approximately 150  $\mu\text{m}$  length at 1.5 mm intervals.

20 Preferably said polymer comprises an epoxy resin, such as EPOTHIN (TM) brand epoxy resin.

The invention also provides a foil sensor produced  
25 according to the above method.

The invention still further provides a foil sensor, comprising:

30 an insulating substrate;  
a thin metal foil bonded to said insulating substrate; and  
at least one trench for defining one or more foil tracks, said trench being equal in depth to the thickness of the foil;  
35 wherein said trench is filled with a polymer so that said one of more foil tracks are electrically isolated from one another.

Sensors that can be made using this method include, for example, linear polarisation resistance gauges, electrochemical impedance spectrometry gauges, corrosion  
5 resistance gauges and pitting fuses.

#### BRIEF DESCRIPTION OF THE DRAWING

In order that the invention may be more clearly ascertained, an embodiment will now be described, by way  
10 of example, with reference to the accompanying drawings, in which:

Figure 1 is a diagram of the three laser path files used in the laser machining of a pair of sensors according to an embodiment of the present invention;

15 Figure 2A is a further diagram of the setup file pattern of figure 1;

Figure 2B is a further diagram of the sensor cutting file pattern of figure 1; and

20 Figure 2C is a further diagram of the sensor backfile slotting file pattern of figure 1.

#### DETAILED DESCRIPTION

According to one embodiment of the present invention, foil sensors were manufactured by the following method,  
25 described by reference to the exemplary manufacture of an aluminium foil sensor.

#### EXAMPLE

Firstly, a thick parent foil material (in the example, aluminium) was machined by alternately machining both  
30 faces of the parent material until a final thickness of 80  $\mu\text{m}$  was achieved. During the machining, a fine pitch vacuum chuck was used to hold the material down, and thermal and stability effects were minimized by using a  
35 large milling machine. The vacuum chuck was machined 'true' before commencing the process.

Machining in this manner removes any surface finish due to processes such as rolling, plating or heat treating, produces a relatively stress free material, and thins the parent material without effecting the material properties.

5

The foil was then prepared for bonding. The foil was degreased and cleaned: in order not to change the surface properties of the foil, it was subjected to the following:

- An acetone wash;
- 10 • A distilled water wash;
- A 30% nitric acid wash;
- A distilled water wash;
- Light wet abrasion of the non-sensor face with 800 grit paper;
- 15 • A distilled water wash;
- Nitrogen drying; and
- Baking for 1 h at 110°C.

20 A chemically resistant adhesive polyester tape was then applied to one face of the foil (i.e. the face ultimately to become the exposed face of the sensor) to protect it from the bond enhancer. A suitable tape, ECONOBREAKER (TM) brand tape supplied by Airtech International, Inc., was used for this purpose.

25

The other face was then dip coated for 15 min with a bond enhancer comprising a 1% silane solution (which had been mixed for 30 min before use).

30 The sample was oven dried at 45°C for 1 h, after which the tape was removed.

The foil was then bonded to the substrate. The prepreg used for the substrate, comprising 0.003 inch (76 µm) FR4  
35 Fibreglass prepreg, was prepared by drying the prepreg in a vacuum oven at 40°C and 2 kPa for 24 h.

The prepared foil was bonded to three layers of prepreg in a bonding press under 3 kN over 150 mm<sup>2</sup>, at 175°C for 1 h. The resulting sensor material was cut into 25 x 75 mm sensor blanks ready for laser machining.

5

A thin chemically resistant coating solution was prepared, so that the sensor blanks could be coated on the sensor side to protect that surface from contamination during sensor processing. This was done by attaching the sensor blank with double sided tape to a laboratory glass slide and positioning the blank/slide centrally on a stationary spin coater. A thick layer of the coating solution was applied and, using a gloved finger, the solution was gently and evenly spread over the surface until an even coat of ~1 mm thickness was produced. The spinner was spun up to 3900 rpm for 10 s to produce a thin even coat of protective film.

20 In this example the coating solution comprised a mixture of 50% LACOMIT (TM) brand vinyl based coating solution and 50% LACOMIT (TM) brand thinner, both by Agar Scientific Limited. Other comparable coating materials that might prove suitable include Crystalbond 509 (TM) brand mounting adhesive and Microshield (TM) brand protectant, both by  
25 Structure Probe, Inc.

The blanks were dried in a 35°C oven for 4 hours.

30 The sensor blanks were laser machined to form trenches in the blanks as follows.

The sensor blank/slide were positioned, using a locating jig, under the laser cutter. Three laser path files were used in the machining:

- 35 1) Setup file;  
2) Sensor Cutting file; and  
3) Sensor Backfile Slotting file.

The blank was translated in the x direction and another pair of sensors was then machined. This continued along the length of the sensor material.

5

Figure 1 is a diagram of the patterns produced by the three laser path files employed in the laser machining of the sensor blank and pair of sensors thereon. This includes the setup file pattern 10, the sensor cutting file pattern 12, and the sensor backfile slotting file pattern 14. For clarity, each pattern is also shown separately in figure 2A (the setup file pattern 10), figure 2B (the sensor cutting file pattern 12 for a single sensor) and figure 2C (the sensor backfile slotting file pattern 14 for a single sensor). In the example shown, the patterns are for machining a pair of twin electrode sensors, for use - for example - as linear polarization resistance gauges or an electrochemical impedance spectrometry gauges.

20

The Setup File: this file produces multiple scans over a non-sensor area of the blank material. From post inspection it was possible to gauge the number of laser scans necessary to cut through the aluminium foil and the fibreglass (as required when cutting slots in the sensor), and the number of scans necessary to cut through the aluminium foil completely but leave the fibreglass essentially intact (as required when cutting the sensor pattern out).

30

The Sensor Cutting file: this file is used to cut the trenches that define the sensor pattern. The number of laser scans is set according to the results of the setup process, that is, the correct number of scans to penetrate the foil but not the fibreglass substrate.

35

The Slotting file: this file puts 150  $\mu$ m back slots at

1.5 mm intervals along the sensor pattern. The number of scans is set to fully penetrate the foil and the fibreglass substrate.

- 5 It will be appreciated by the skilled person that, during laser machining, ablation products form on the sensor face close to the trench edge. These were removed by subjecting the sensors to the following:
- Ultrasonic cleaning for 2 min in a 20% NaOH solution;
  - 10 • Immersion in 70% nitric acid until reaction (evidenced by bubbling) stops;\_
  - A distilled water wash; and
  - Nitrogen drying.

- 15 The protective film of LACOMIT (TM) brand coating solution protects the bulk of the surface from chemical attack during this removal of ablation products.

- 20 The protective film covering the sensor was then removed with a suitable solvent, LACOMIT (TM) brand Remover by Agar Scientific Limited, a xylene based product selected so as not to effect the sensor surface.

- 25 Trench filling was conducted as follows. A high temperature polyester adhesive tape was applied to the sensor face. FLASHBREAKER 2R (TM) brand tape by Airtech International, Inc. was selected for this purpose, as high temperature tape has fewer volatile substances so does not outgas to as great extent as some alternatives.

- 30 The sensor was taped along its edge, fiberglass side up, to the base of a shallow container and dried in a vacuum oven for 12 h at 60°C at 2 kPa.

- 35 The oven was vented and a low viscosity epoxy resin (in this example, EPOTHIN (TM) brand epoxy resin by Buehler Ltd) was introduced from a container above the sensor.

(This container had a drain plug that can be operated from outside the chamber.) The vacuum was reestablished and the epoxy allowed to outgas for a few minutes.

5 Care was exercised in the outgassing of the epoxy resin; the vacuum was hard enough to remove air introduced during the epoxy mixing, but not so hard as to 'boil' the low density components out of the epoxy. Also, outgassing was kept brief (between 10 to 15 min ) so that the epoxy did  
10 not start to cure.

While still under vacuum and using remote control, the resin was allowed to flow into the sensor, that is, the sensor was essentially immersed in the resin.

15 The oven was vented, to force the resin to flow through the back slots and into the trenches.

In the final assembly stage, the sensors were removed from  
20 the resin and excess resin was removed. The sensors were then cured in an oven at 50°C for 24 h.

The protective tape was removed, and the surface cleaned with turpentine to remove any residual adhesive, washed  
25 with ethanol, rinsed in distilled water and dried with nitrogen.

Finally, the completed foil sensors were guillotined into individual elements.

30 Thus, foil sensors manufactured according to the present invention can compose the same material as that which they are intended to monitor; the ability to use material that is the same as the monitored structure simplifies the  
35 correlation of sensor results with what is occurring on the structure. For example, corrosion activity on an aluminium alloy structure can be correlated with a

corrosion sensor made of precisely the same material.

Such foils sensors can be made with fine feature size.  
The ability to machine stable structures in the tens of  
5 microns range enables electrical parameters to be scaled  
to a point where they can be reliably measured.

Multiple types of corrosion sensor can be manufactured  
using the process, including corrosion sensors (whether  
10 electrochemical or resistance (labyrinth) sensors),  
fatigue gauges and continuity gauges. These sensors can  
also be situated under paint and sealant beads

Furthermore, the material is preferably milled to size,  
15 rather than rolled or chemically etched to size. Milling  
allows the material to retain important properties,  
whereas these other two methods alter such properties.

Modifications within the scope of the invention may be  
20 readily effected by those skilled in the art. It is to be  
understood, therefore, that this invention is not limited  
to the particular embodiments described by way of example  
hereinabove.

25 Any reference herein to prior art is not intended to imply  
that such prior art forms or formed a part of the common  
general knowledge.

Dated this 5th day of December 2003

30 THE COMMONWEALTH OF AUSTRALIA

By their Patent Attorneys

GRIFFITH HACK

Fellows Institute of Patent and

Trade Mark Attorneys of Australia

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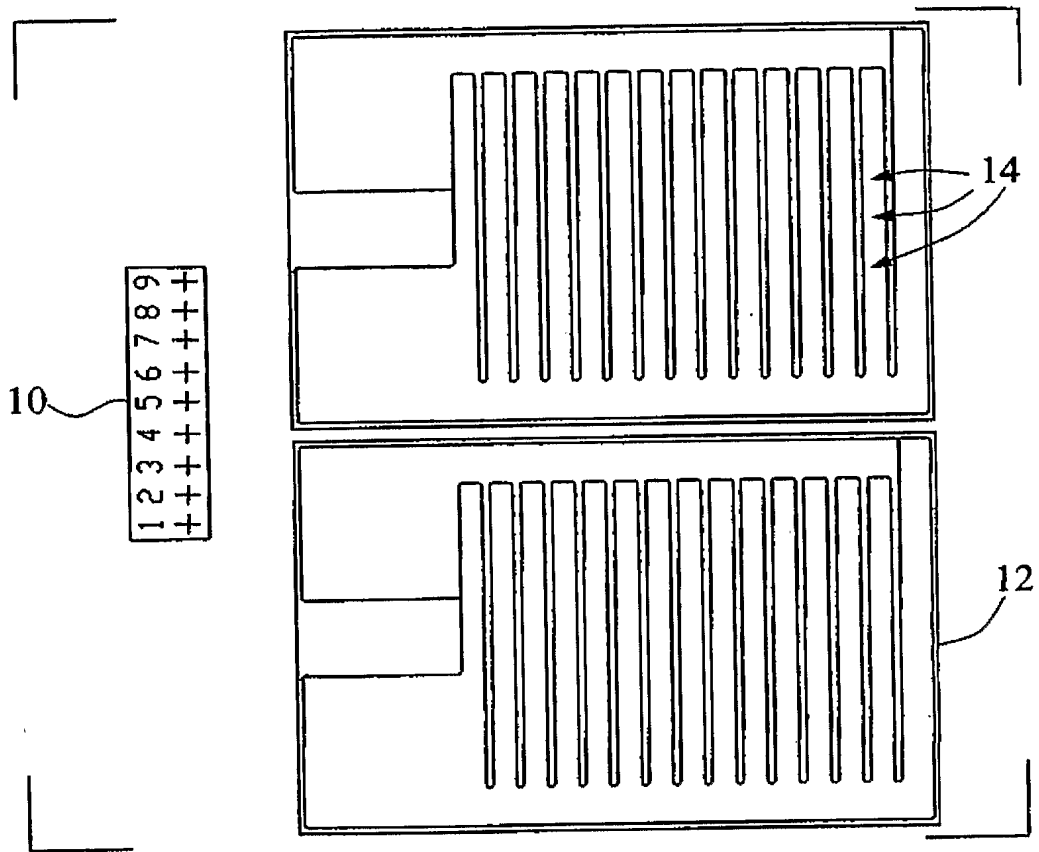


Figure 1

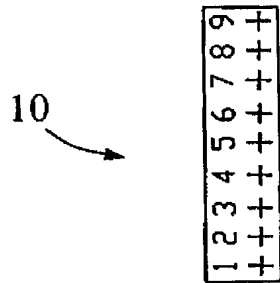


Figure 2A

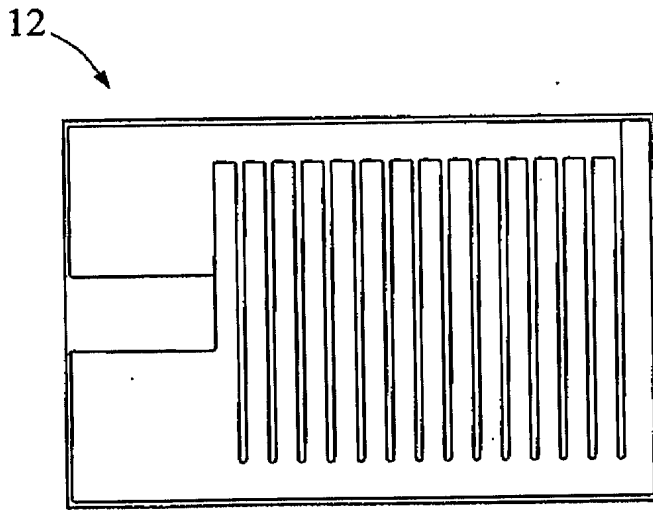


Figure 2B

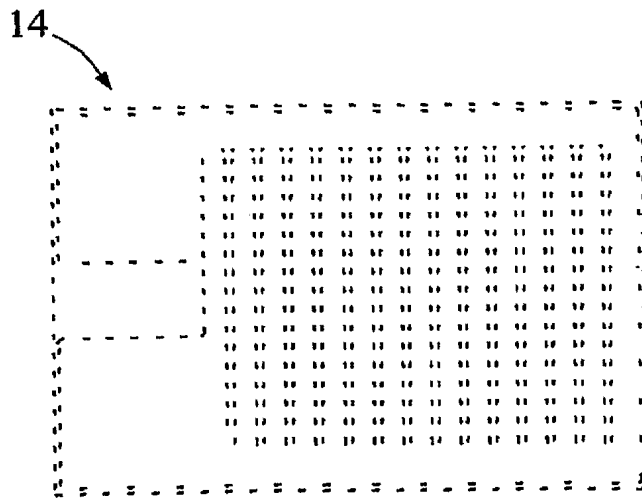


Figure 2C